Soil microbial biomass and its controls

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Abstract: Microbial biomass represents a relatively small standing stock of nutrients, compared to soil organic matter, but it can act as a labile source of nutrients for plants, a pathway for incorporation of organic matter into the soil, and a temporary sink for nutrients. This review describes several factors controlling the dynamics of soil microbial biomass. These factors mainly include organic carbon and nitrogen limitation, residue and nutrient management, differences in plant species, soil texture, soil moisture and temperature. On the basis of detailed analysis, it is reasonable that future research would be focused on the impact of land use change on soil MB in tropical and subtropical ecosystems.

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Introduction

Soil microorganisms are the main mediators of carbon turnover in soil, and part of the organic carbon and nutrient pool are called microbial biomass (Zogg *et al.* 2000). The amount of C in the soil microbial biomass mostly accounts for 1%–3% of the total soil organic C, and its turnover time is less than one year (Dilly *et al.* 2003). Because the microbial fraction changes comparatively rapidly, microbial biomass can provide an early indication of slow changes in organic matter content.

Although microbial biomass is clearly important to a series of soil processes, its fate and potential response to change in soil texture, environmental conditions and land use have not been extensively studied, and the information appears fragmented and sometimes contradictory. Controls on microbial biomass had been studied in many laboratory experiments using disturbed soil samples, but fewer studies had focused on the dynamics of microbial biomass under field conditions. Additionally, most of the studies dealing with controls on microbial biomass in soils focus on microbial biomass carbon (MBC); information on soil microbial biomass nitrogen (MBN) and microbial biomass phosphorus (MBP) is much less. The main objectives of this review are to summarize the recent literature regarding controls on microbial biomass in soils, and to identify the issues that should be addressed in future research.

Controls on microbial biomass

Soil microbial biomass can act as a significant source or sink for soil carbon and nutrients and potentially influence the amounts of organic C and N retained within soil organic matter (SOM). Therefore, it is important to understand the controls on microbial abundance, turnover, and carbon and nutrient sequestration (Templer *et al.* 2003). Soil microbial biomass is related to several factors, such as organic C and N limitation, residue and nutrient management, differences in plant species, soil texture, soil moisture and temperature.

Carbon and nitrogen limitation

Microbial biomass is strongly related to organic matter content of soil. Systems with high organic matter inputs and available soil organic matter tend to have higher microbial biomass contents because they are preferred energy sources for microorganisms (Landgraf *et al.* 2002). Thus the addition of readily decomposable C sources such as glucose or sucrose to the soil results in a rapid rise in microbial growth and activity. Allen & Schlesinger (2004) performed an assay of C limitation to soil microbial biomass in intact cores of mineral soil collected from three North Carolina loblolly pine (*Pinus taeda*) forests. They observed that microbial biomass C in the mineral soil increased when C was added. This result is consistent with the conclusions of Zak *et al.* (1994). Microbial biomass and activity may also be limited by the availability of N (Wardle 1992). Gallardo & Schlesinger (1994) found that addition of NH_4NO_3 increased microbial biomass N in the forest floor of a warm-temperate hardwood forest. Kuikman *et al.* (1991) showed that when mineral N was added to the soil, the microbial population started to decompose substrates with a higher ratio of C to N, suggesting that decomposition of high C/N substrates can be limited by N availability. Jonasson *et al.* (1996) demonstrated that addition of inorganic N stimulated microbial activity in arctic soils. To assess the importance of soil C and N in limiting magnitude of microbial biomass in various ecosystems, 25 data sets in 22 published literatures were re-analyzed by Wardle (1992). He found that microbial biomass C, substrate C and N were highly positively correlated. Also, the proportion of organic C immobilized in microbial biomass was more positively correlated to substrate N than to substrate C, indicating that in most systems soil N rather than C appeared to influence immobilization of organic C into microbial biomass.

Residue and nutrient management

Microbial biomass growth and function are related to substrate C input into systems and amending the soil with crop residues always induces an increase in soil microbial biomass. For example, Entry *et al.* (1986) observed that levels of soil microbial

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biomass increased when residues were left on the site following harvesting, and suggested that the increase was partly due to the substantial input of readily decomposable organic matter. The root systems of thinned trees could also contribute to increased microbial development, since they represent a readily available source of C (Thibodeau *et al.* 2000). Powlson *et al.* (1987) found that incorporating straw and stubble in soil resulted in higher biomass, compared to soils where straw and stubble were burnt for similar periods. Also, biomass C roughly doubled within 7 days after field incorporation of straw but remained constant in soils that received no straw (Ocio *et al.* 1991). In addition, substrate input increases microbial biomass pools and is sustained for considerable periods before returning to equilibrium conditions. Follett (1997) explained that generally microbial biomass is in equilibrium with periodic flushes of activity and growth. Much of the yearly throughput of organic C is used to maintain microbial populations. If there are no or limited inputs of C, microbial biomass would utilize available organic C in soil until supplies become increasingly depleted, then the size of microbial biomass pool would decrease. At present, information about the mechanisms by which residue management affect soil microbial biomass is still fragmented, especially regarding the amendment of forest soils with harvest residues and the long-term effects of amendments on native soil microbial biomass.

Nitrogen fertilization may either reduce or cause significant stimulation in microbial biomass. Microbial biomass exhibits variable responses to nutrient management (Wardle 1992). Several studies have indicated that increased N fertilization rates were associated with reduced microbial biomass C (McAndrew *et al.* 1992; Ladd *et al.* 1994; Smolander *et al.* 1994; Biederbeck *et al.* 1996). Other studies have found that biomass C in soils receiving N fertilization was higher than that in soils no receiving N fertilization (Shen *et al.* 1989; Paul & Beauchamp, 1996; Wang *et al.* 2004). Only a few studies reported no clear influence of N fertilization on microbial biomass C (Banerjee *et al.* 1999; Liu *et al.* 2003). It appears that both in forest and agricultural soils, the net effects of N fertilization on microbial biomass have not yet been clearly established. Further, the mechanisms responsible for the change of the microbial biomass following application of N fertilization are unknown.

Plant species

Plants provide C sources in litter, plant C transfers and rhizodeposits, which support microbial biomass growth. Microbial biomass can decrease with increasing ratios of C/N or lignin/N in organic tissue (Prescott 1996; Taylor *et al.* 1989). Since plant species differ in quality of leaf litter (e.g. C/N ratio), soil microbes associated with different plant species often have variable amounts of microbial biomass (Bauhus *et al.* 1998; Liu *et al.* 2001). Further, carbon transfers through the plant-soil system, and root-derived C substrates in the rhizosphere substantially stimulate microbial biomass by continuously feeding the soil system with readily available forms of C and N rather than the episodic inputs of plant organic matter (Wardle 1992). A few studies have directly compared the influence of plant species on soil microbial biomass. Even under similar environmental and soil conditions, different plant species influence microbial biomass greatly. Microbial biomass C in four vegetation types: forest, savanna, cropland and mine spoil in India were assessed by Srivastava *et al.* (1991). They found that microbial biomass C was highest in forest, compared to other vegetation types, and ranged from 250 $\mu g \cdot g^{-1}$ in cropland soil to 609 $\mu g \cdot g^{-1}$ in forest soil. In China, microbial biomassC in 0-15cm depth differed in several vegetation types as follows: *Eucalyptus exserta* forest, <20 to 140 $\mu g \cdot g^{-1}$; mixed forest with legume, 115 to 186 $\mu g \cdot g^{-1}$ and secondary monsoon forests, 188 to 350 $\mu g \cdot g^{-1}$ (Mao *et al.* 1992). Wang *et al.* (2004) investigated the levels of microbial biomass carbon (MBC), nitrogen (MBN) and phosphorus (MBP) in the soil profiles of five different vegetation systems including bare area (Br), Bamboo (Bmb), Chinese fir (CF), Citrus Orchard (Ctr) and Rice field (Rf). The MBC and MBN levels in surface soil (0-20 cm) for the Bmb system were both higher (162.38 $\mu g \cdot g^{-1}$ and 53.29 $\mu g \cdot g^{-1}$ respectively) than those in the other systems. The order of soil MBP levels from highest to lowest was as follows: Bmb>CF>Ctr>Rf>Br. According to the results of Hofman *et al.* (2004), microbial biomass was significantly lower in arable soils, moderate in grassland soils and highest in forest soils. This observation is consistent with the previously generally accepted results (e.g. Wardle 1992; Wardle 1998). Higher microbial biomass levels in grassland/pasture than those in arable crops were attributed to soil structural differences, while higher microbial biomass levels in forests than those in arable crops were attributed to the quantity and quality of organic inputs (Wardle 1992). Overall, the available information consistently suggests that both in forest and agricultural soils, plant species influences soil microbial biomass. Nevertheless, additional research is required to better understand how plant species influences microbial biomass concentration and composition.

Soil texture

Carbon turnover, transformations and formation of microbial biomass are controlled by soil texture and are often linked to soil clay content (Bauhus *et al.* 1998). Merckx *et al.* (1985) and Wardle (1992) attributed the role of clay minerals to different mechanisms as follows. Clay minerals can adsorb organic materials in soils, buffer change in pH and form envelopes around bacterial cells, which restricts the degradation of organic materials or offers protection against microbivory.

Anderson & Domsch (1995) provided evidence to support the close relationship between soil organic carbon and microbial biomassC and between clay fraction and soil organic carbon. Clay minerals bind organic C and microbial components and control microbial processes. The influence of clay has been variously demonstrated. For example, decomposition was more rapid and proportion of applied ^{14}C in microbial biomass in sandy loam soil was lower than that in clay soil (Van Veen *et al.* 1987). Amounts of ^{14}C incorporated in microbial biomass in clay soils were larger than those in sandy soils (Van Veen *et al.* 1989) and the turnover of root-derived C through microbial biomass was relatively fast and constant in sandy soil but slow in silt clay loam soil (Merckx *et al.* 1985). Gregorich *et al.* (1991) reported that soils with greater amounts of clay maintained higher quantities of biomass carbon. However, Kaiser *et al.* (1992) reported a weak correlation between biomass C and clay content and a negative correlation between microbial biomass C and sand content. At present, our knowledge of the influence of soil texture on microbial biomass is still limited, especially in China.

Soil moisture and temperature

In addition to substrate quality and quantity, environmental conditions can also affect microbial biomass and activity (McGill *et al.* 1986). Moisture conditions are a major factor controlling survival and activity of microorganisms in the soil. Adequate soil moisture increases microbial biomass and activity. Beyond field

capacity, microbial activity decreases with increasing moisture, due to limited oxygen availability (Killham 1994). Rosacker & Kieft (1990) found that microbial biomass increased when grassland soil was moistened to 50%–60% water holding capacity; but microbial biomass declined greatly as the soils were subjected to progressive drying conditions. This is consistent with the results reported by Chen *et al.* (1995).

Microbial activity in the soil is not only affected by soil moisture content and water potential at the time of measurement, but also by the previous moisture conditions. One of the most consistent findings in both field and laboratory studies is that microbial biomass and activity increase following wetting dried soil (Pulleman & Tietema, 1999). For example, Van Gestel *et al.* (1991) reported that MBC decreased by 26%–30% during soil drying and increased to 77%–84% of untreated controls during incubation after rewetting in an Alfisol and Vertisol. Scheu & Parkinson (1994) gave the possible explanations for the increase in microbial biomass-C during rewetting cycles. Many soil microbes do not tolerate low moisture conditions and perish during drying from desiccation stress. While following wetting dried soil, decomposition of killed microbes and enhanced availability of substrates to microbial attack cause the flush in C mineralization immediately. Our study on soil microbial biomass C in a natural forest of *Castanopsis kawakamii* and adjacent plantations of *C. kawakamii* and Chinese fir (*Cunninghamia lanceolata*) in Sanming, Fujian, China also indicated the significant response of microbial biomass to air-drying and rewetting in soils (Yang 1998).

On the other hand, different reports of temperature effects on microbial biomass showed that microbial biomass are increased or reduced with temperature increases, or no effects. For instance, Verburg *et al.* (1999) expected microbial activity to increase at elevated temperatures, which could lead to either the production of more microbial biomass and/or biomass with a lower ratio of C to N. In contrast, Domisch *et al.* (2002) observed that microbial biomass C and N in the peat soil decreased at higher soil temperature. While Contin *et al.* (2000) and Kandeler *et al.* (1998) found that both microbial biomass C and N were relatively insensitive to temperature, and no effects of temperature on microbial biomass C and N. Overall, a trend of increasing microbial biomass content with increasing temperature is more obvious in laboratory experiments than in field studies. Climatic and hydrological conditions, and soil texture and other soil properties can modify and even mask the temperature response of microbial biomass in the field.

Conclusions and prospect

By reviewing the studies of controls on soil microbial biomass, we could see that factors influencing soil microbial biomass include soil properties (e.g. soil texture, moisture and temperature) and external factors (e.g. C and N limitation, manipulation of residue and nutrient and plant species effect). Despite intensive research on soil microbial biomass in the last decade, the bias between field and laboratory findings is most critical. In China, more studies reported on microbial biomass in agricultural soil and on the effects of fertilization on its dynamics. However, the amount, nature, and fate of the microbial biomass in forest soils remain unclear, especially in the field. Therefore, future research should be focused on comprehensive studies dealing with the relationship between soil microbial biomass dynamics and environmental factors in the field. In addition, future research should concentrate on: (i) quantification of the effects of land use on in situ microbial biomass dynamics in soils; (ii) comparison of the dynamics of MBN and MBP with MBC; (iii) controls on microbial biomass dynamics in soils of different climate zones, and especially tropical and subtropical area; (iv) developing isotopic or other analyses that help measurement of content and dynamics of microbial biomass in soils.

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